

# Results of a search for $2\beta$ -decay of $^{136}\text{Xe}$ with high pressure copper proportional counters in Baksan Neutrino Observatory INR RAS

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Search for  $\beta\beta$ -decay of  $^{136}\text{Xe}$  with two high pressure proportional counters is carried out in Baksan Neutrino Observatory. The experiment is based on comparison of spectra measured with natural and enriched xenon. The measured half life is equal to  $T_{1/2} = 5.5^{+4.6}_{-1.7} \cdot 10^{21}$  yr (67% C.L.) for  $\beta\beta 2\nu$  decay mode. No evidence has been found for neutrinoless  $\beta\beta$ -decay. The decay half life limit based on data measured during 17280 h is  $T_{1/2}(\beta\beta 0\nu) \geq 4.9 \cdot 10^{23}$  yr (90% C.L.).

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## I. INTRODUCTION

The experimental investigation of the  $\beta\beta$ -decay of  $^{136}\text{Xe}$  has been started more than 20 years ago. But both two neutrino and neutrinoless modes of this process for  $^{136}\text{Xe}$  was not observed. The results of last experiments are presented in Table I. The theoretical estimations of half lifetime for  $\beta\beta 2\nu$ -decay are presented in Table II. It is necessary to mention that in [4] only one spectrum (measured with enriched  $^{136}\text{Xe}$ ) was obtained. To calculate their limit it was assumed that at any effect/background ratio in the energy range under investigation the effect did not exceed the actually measured background increased by a systematic error given in  $\sigma$  units ( $\sigma$  is a standart deviation). In our work the measurements were performed with both enriched xenon and natural xenon simultaneously.

## II. EXPERIMENTAL SETUP

The measurement was carried out with two high pressure copper proportional counters (CPC N1 and CPC N2). While one of them is filled with enriched xenon (93% of  $^{136}\text{Xe}$ ), the other one is filled with natural xenon depleted by light isotopes (9.2% of  $^{136}\text{Xe}$ ). Both CPC-s are surrounded by passive shield consisting of 20 cm of copper (keept in underground facilities over 20 yr), 8 cm of borated polyethylene and 23 cm of lead (see Fig.1a). The installation is located in the deep underground laboratory of the BNO INR RAS at the depth 4900 m w.e, where the flux of muons is decreased by factor  $10^7$  and evaluated as  $2.23 \cdot 10^{-9} \text{ cm}^{-2} \text{ s}^{-1}$  [9]. The parameters of the CPC-s are: working pressure - 14.8 bar, fiducial volume - 8.39 l, biased voltage - 3900 V. Signals were read out from the end of anode wire through charge sensitive preamplifier (PA). Then they were supplied to the digital oscilloscope through amplifier (see Fig.1b).

To exclude the influence of PA capacity charge decay

the pulses were reconstructed by software (taking into account this decay). The amplitudes of the reconstructed pulses (A) were used to construct the energy spectrum. For detailed analysis the following pulse shape parameters was used: the pulse rise time ( $\tau$ ) and parameter  $\delta$  defined as:

$$\delta = 1000 \cdot \left(1 - \frac{\sum (y_i - g_i)^2}{\sum (y_i - \bar{y})^2}\right),$$

where the  $y_i$  is value of normalized current at the point  $i$ ,  $g_i$  - value of gaussian at the same point,  $\bar{y}$  - mean value of the normalized current in fitting region. The region of fitting by gaussian is restricted by point of pulse beginning and point where the reconstructed pulse get a value  $0.9 \cdot A$ . In Fig.2 samples of the pulses are shown.

## III. DATA TREATMENT

From previous experiments [3] it was seen that significant part of the counters background is due to  $\alpha$ -particles produced in gas volume. To define parameters of  $\alpha$ -particle events the measurement of background of one of CPC-s filled with xenon with admixtures of  $^{222}\text{Rn}$  ( $\alpha$ -particles with energy of 5.49 MeV, 6.02 MeV and 7.69 MeV) was performed. The results of this measurement are presented in [10].

Main measurements performed in 4 runs. In the first run CPC N1 was filled with natural xenon and CPC N2 with enriched xenon. Duration of the run was  $\geq 4000$  h. Then first CPC was refilled with enriched xenon, second one with natural xenon, after each run the refilling procedure was repeated. Such a procedure allows eliminate systematic error from possible differences between counters. To exclude the contribution of  $^{222}\text{Rn}$  (which goes from gas purification system) to the CPC-s background the data of the first 500 h of measurements were not used for analysis. The calibration of the counters was carried out every  $\sim 4$  weeks ( $\sim 700$  h). The samples of calibration are presented in Fig.3.

TABLE I. The results of some experiments for the search of  $\beta\beta$ -decay of  $^{136}\text{Xe}$ 

Experiment	$T_{1/2} (\beta\beta 2\nu)$ , yr	$T_{1/2} (\beta\beta 0\nu)$ , yr
Gran Sasso [1]	$\geq 1.6 \cdot 10^{20}$ (95% C.L.)	$\geq 1.2 \cdot 10^{22}$ (95% C.L.)
GOTTHARD [2]	$\geq 3.6 \cdot 10^{20}$ (90% C.L.)	$\geq 4.4 \cdot 10^{23}$ (90% C.L.)
BNO INR RAS [3]	$\geq 8.5 \cdot 10^{21}$ (90% C.L.)	$\geq 3.1 \cdot 10^{23}$ (90% C.L.)
DAMA/LXe [4]	$\geq 1.0 \cdot 10^{22}$ (90% C.L.)	$\geq 1.2 \cdot 10^{24}$ (90% C.L.)

TABLE II. The theoretical estimations for  $\beta\beta 2\nu$ -decay of  $^{136}\text{Xe}$ 

Authors	$T_{1/2} (\beta\beta 2\nu)$ , yr
E. Caurier et al. [5]	$2.1 \cdot 10^{21}$
O.A. Rumyantsev, M.G. Urin [6]	$1.0 \cdot 10^{21}$
A. Staudt et al. [7]	$1.5 \cdot 10^{19} \div 2.1 \cdot 10^{22}$
P. Vogel and M.R. Zirnbauer [8]	$1.5 \cdot 10^{20} \div 1.5 \cdot 10^{21}$

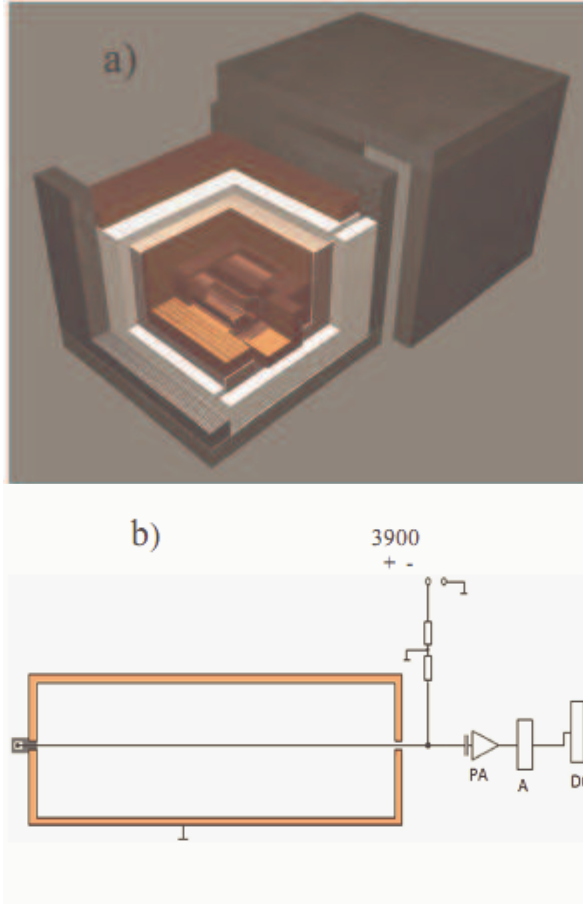


FIG. 1. a) - the schematic view of the installation and b) - the electric scheme of installation, PA - preamplifier, A - amplifier, DO - digital oscilloscope.

Distribution of the background events (3300 h of measurements),  $^{22}\text{Na}$  and  $^{137}\text{Cs}$  source events versus energy- $\tau$  and energy- $\delta$  are presented in Fig.4(a-c) and Fig.5(a-c) respectively. It is seen that distribution of the background events differ from  $^{22}\text{Na}$  events significantly. This difference is clearly seen in distribution of events versus

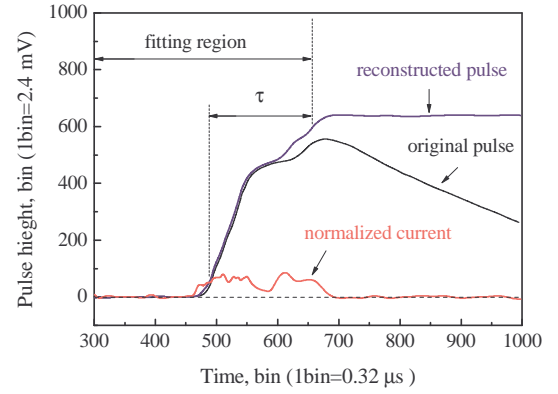
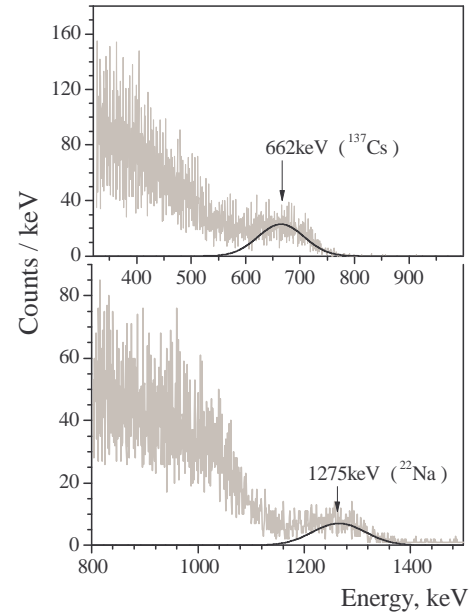


FIG. 2. The samples of the pulses (initial pulse, reconstructed pulse and normalised pulse).

FIG. 3. The calibration spectra of  $^{137}\text{Cs}$  and  $^{22}\text{Na}$  sources.

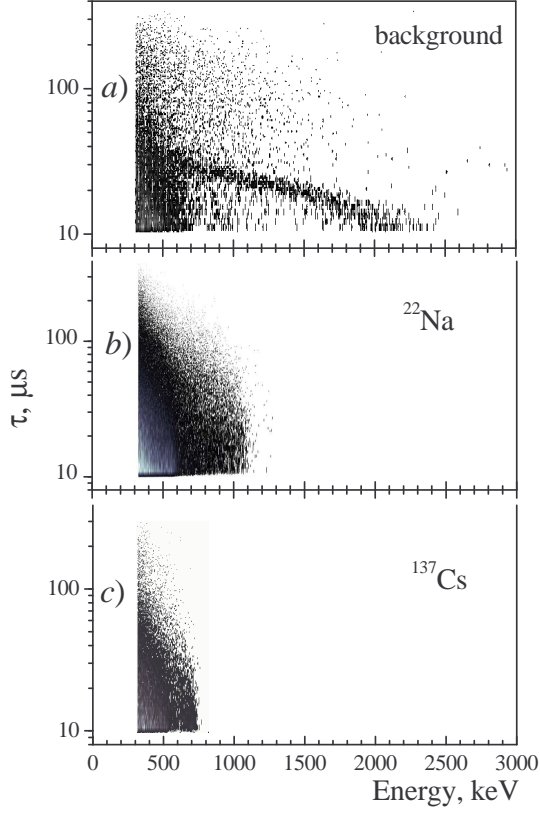


FIG. 4. Distribution of events versus energy and  $\tau$  - *a, b* and *c* for the background ( $\Delta t = 3300$  h),  $^{22}\text{Na}$ - and  $^{137}\text{Cs}$ -source respectively.

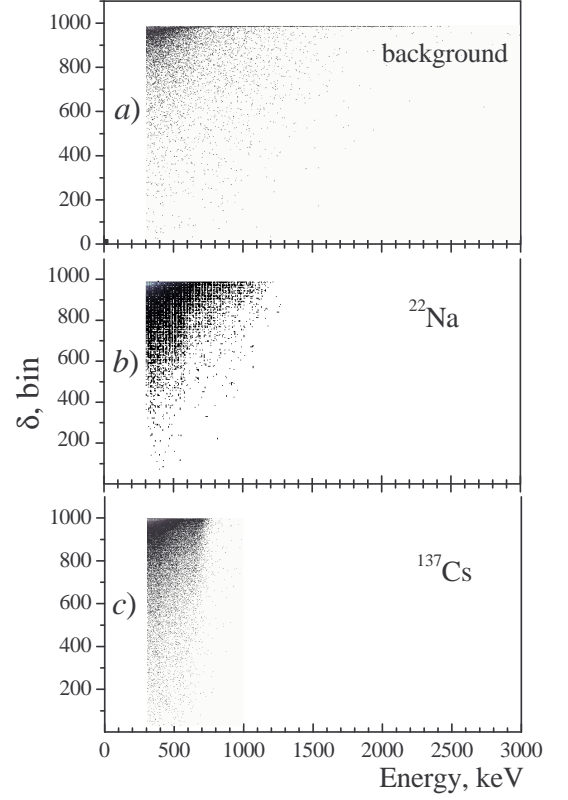


FIG. 5. Distribution of events versus energy and  $\delta$  - *a, b* and *c* for the background ( $\Delta t = 3300$  h),  $^{22}\text{Na}$ - and  $^{137}\text{Cs}$ -source respectively.

TABLE III. The number of events with energy  $0.7 \div 2.48$  MeV, registered in CPC N1 and CPC N2 during 3300 h of measurements for each run.

run	CPC N1	CPC N2
1	2396 ( $^{nat}\text{Xe}$ )	2591 ( $^{136}\text{Xe}$ )
2	1953 ( $^{136}\text{Xe}$ )	1968 ( $^{nat}\text{Xe}$ )
3	1259 ( $^{136}\text{Xe}$ )	1224 ( $^{nat}\text{Xe}$ )
4	1383 ( $^{nat}\text{Xe}$ )	1477 ( $^{136}\text{Xe}$ )

energy and  $\delta$  for energy greater then 800 keV (see Fig.6.).

It was used to separate  $\alpha$ -particle events and electron events (events from  $\alpha$ -particles have  $\delta > 990$ , most events from electron have  $\delta \leq 990$ ). The transformation of the background spectrum after such rejection is seen in Fig.7.

#### IV. RESULTS

The effect from  $\beta\beta 2\nu$ -decay of  $^{136}\text{Xe}$  is determined with comparison of total spectra measured with enriched and natural xenon (see Fig.8). Number of events in the energy region  $0.7 \div 2.48$  MeV registered by CPC N1 and CPC N2 at 3300 h in each run of measurements are presented in Table III. The evaluated effect is  $309 \pm 119(\text{stat}) \pm 72(\text{syst})$ . The total deviation is

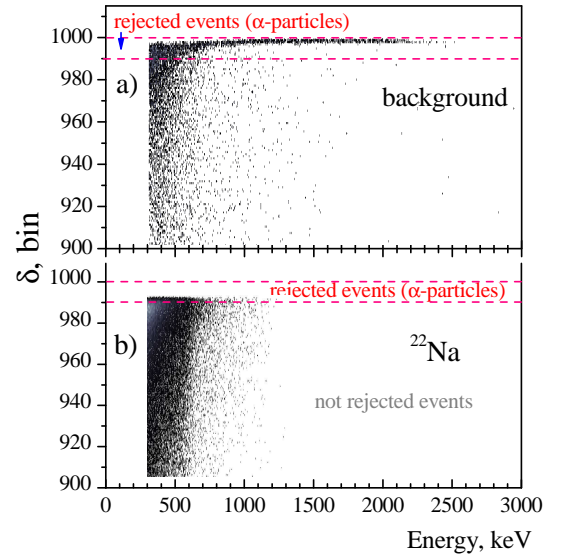


FIG. 6. Distribution of the background events and  $^{22}\text{Na}$ -source versus energy and  $\delta$  in the region for  $\delta > 900$  (cut of the events with  $\delta > 990$  is shown).

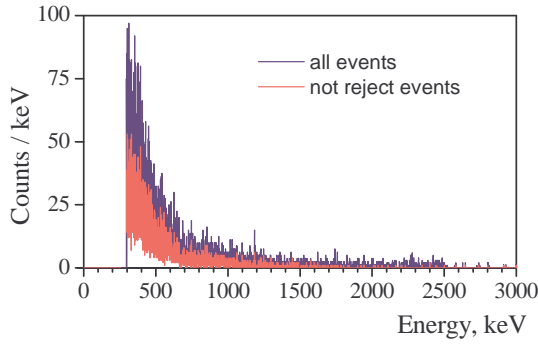


FIG. 7. The energy spectra measured during 4900 h, blue curve - before rejection of pulses with  $\delta > 990$ , orange curve - after rejection.

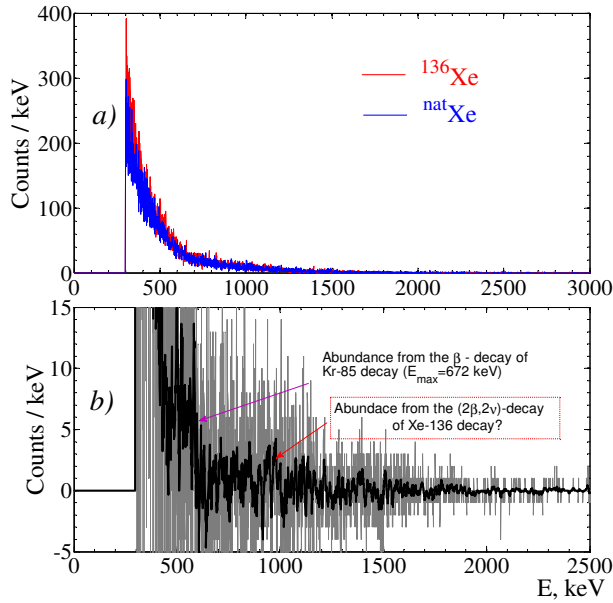


FIG. 8. a) - the energy spectra measured during 13200 h and b) - difference in spectra between enriched and natural xenon.

$$\sigma_{tot} = \sqrt{\sigma_{stat}^2 + \sigma_{syst}^2} = 139. \text{ So effect is } +2.22\sigma_{tot}. \text{ Tak-}$$

ing into account efficiencies and the different content of  $^{136}\text{Xe}$  in two samples we obtain the half lifetime for  $\beta\beta 2\nu$ -decay:

$$T_{1/2}(\beta\beta 2\nu) = \frac{\ln(2) \cdot t \cdot N \cdot \epsilon}{309 \pm 139} = 5.5_{-1.7}^{+4.6} \cdot 10^{21} \text{ yr (67\% C.L.)},$$

where:  $t = 13200 \text{ h} = 1.507 \text{ yr}$  - measurements time,  $N = 3.06 \cdot 10^{24}$  - difference in quantity of  $^{136}\text{Xe}$  atoms in xenon samples,  $\epsilon = 0.535$  - efficiency after rejection of events with  $\delta > 990$  and  $E < 700 \text{ keV}$ .

To evaluate the  $\beta\beta 0\nu$ -effect the energy spectra in region  $2312 \div 2646 \text{ keV}$  were analyzed. The data for the analysis  $0\nu$ -mode have been taken for 17280 hours of mea-

TABLE IV. The number of events with energy  $2312 \div 2646 \text{ keV}$ , registered in CPC N1 and CPC N2 for four series of measurements of the counter background.

Run	Meas. time, hours	CPC N1	CPC N2
1	3300	2 ( $^{nat}\text{Xe}$ )	0 ( $^{136}\text{Xe}$ )
2	4170	6 ( $^{136}\text{Xe}$ )	1 ( $^{nat}\text{Xe}$ )
3	6410	1 ( $^{136}\text{Xe}$ )	4 ( $^{nat}\text{Xe}$ )
4	3400	3 ( $^{nat}\text{Xe}$ )	1 ( $^{136}\text{Xe}$ )

surements. This energy region is determined from calculated energy resolution for 2479 keV electrons ( $R=7.0\%$ ,  $2\sigma = 147 \text{ keV}$ ) and systematic error in definition of peak position ( $\pm 20 \text{ keV}$ ). Number of events in the energy region  $2312 \div 2646 \text{ keV}$  registered by CPC N1 and CPC N2 in each run of measurements are presented in Table IV. Using recommendation given in [11] and assuming that mean background is 10 events and measured one is 8 events, we obtain:

$$T_{1/2}(\beta\beta 0\nu) \geq \frac{\ln(2) \cdot t \cdot N \cdot \epsilon}{4.22} = 4.9 \cdot 10^{23} \text{ yr (90\% C.L.)},$$

where  $t = 17280 \text{ h} = 1.97 \text{ yr}$  and  $\epsilon = 0.5$ .

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